THE ELECTRON METHOD OF STANDARDIZING THE CORONAS OF CLOUDY CONDENSATION.

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1. *Introductory.*—Last year I published some preliminary experiments[1] in which the coronal display of the fog chamber was standardized by aid of the value of Thomson's electron, $10^{10}e = 3.4$ electrostatic units, and of the known velocity of the ions. Later similar experiments were made in terms of the former datum and the decay constants of the ions, though this method is not here to be considered. In the experiments in question a separate leaded condenser was used to determine the ionization, while the nucleation was measured in a cylindrical fog chamber. The data, though necessarily rough, owing to the dampness of the room in the summer time, when used for the determination of e by aid of my earlier and independent constants of coronas, nevertheless gave a series of promising values. In the paper cited it was assumed that the whole current due to both positive and negative ions is measured. If, however, the current observed is due to negative ions, while the negative ions only were caught in the fog chamber used, as now appears probable, then the data would be ($\dot{V}$ denoting the fall of potential per second, dV/dr the average field, all referred to volts, N the number of nuclei (negative ions), per cubic centimeter).

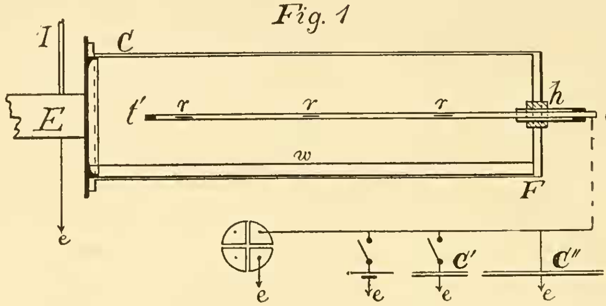
dV/dr	$10^3 \dot{V}/V$	N	$10^{10}e$
1.0	40	150,000	3.3
.7	50	185,000	3.2
.7	60	210,000	3.7
1.2	137	570,000	2.9

where the velocity of negative ions in a unit field of dry air is taken as $v = 1.87$ cm./sec.

[1] *American Journal of Science*, XXVI., 1908, p. 87; *idem*, p. 324.

In the following experiments I have returned to the measurements of *N* in terms of *e* and the velocities of the ions, modifying the method by using the cylindrical fog chamber both as an electrical condenser for the measurement of current, as well as for the specification of the number of ions in action by aid of the coronas of cloudy condensation.

Fig. 1



2. *Apparatus.*—This consists of a cylinder of glass *C, F,* about 45 cm. long, 13.4 cm. internal diameter, closed at one end *F* and provided with a brass cap *C,* with exhaust *E* and influx attachments *I,* in the usual way. There is a layer of water *w* at the bottom. The glass must be scrupulously clean within; and this is best secured by scouring with a probang of soft rubber under water, until the water adheres as an even film on shaking. The fog chamber is put to earth, as at *e*.

The end *F* is perforated at *h*, to receive the aluminum tube *tt′*, closed at *t′* and open at *t,* 40 cm. long and .64 cm. external diameter. Sealed tubelets of radium *r, r,* . . . may be placed at intervals within this tube to ionize the surrounding wet air. The walls being about .1 cm. thick, β and γ rays are wholly in question. Neither emanation nor α rays escaped the double thickness of aluminum. The tube *tt′* is grasped at *t* by a sheath of hard rubber with an annular air space and fixed in place by a rubber cork. If care be taken to keep the tube in dry air except when in use, there is no conduction leakage of consequence.

The end *t,* moreover, is placed in connection with a Dolezalek electrometer, by aid of a thin wire (not shown) running axially within an earthed tin drain pipe and away from the fog chamber, to escape the action of γ rays as much as possible. In fact their combined effect does not exceed 2 per cent. and is determined in special measurements.

The keys to the electrometer,[2] etc., were all placed on pillars of hard rubber and actuated by long wooden rods from a distance. So far as possible the electrical wires of the room were surrounded by earthed pipes, but it was not practicable to carry this out completely so that a method of correction appears in the work below. Even when the electric lighting circuit was completely cut out, the electrostatic drift in question remained.

The measurements were standardized and the electric system charged by a Carhart-Clarke cell.

The radium tubelets used were as follows:

No. I,	100 milligrams,	strength	10,000 ×
No. II,	10 milligrams,	strength	200,000 ×
No. III,	100 milligrams,	strength	10,000 ×
No. IV,	100 milligrams,	strength	7,000 ×
No. V,	100 milligrams,	strength	20,000 ×

3. *Electrical Condensers.*—To give the fall of potential a suitably small value relatively to the period of the damped drop of the needle, a number of auxiliary condensers, C', C'', Fig. 1, are needed. It suffices, however, to measure three capacities, viz.,

1. That of the cored fog chamber alone, c;
2. That of a relatively large auxiliary condenser, including the electrometer, the piped wires and the fog chamber, $C''+c$;
3. That of a standard condenser, C', for reference.

In the present paper C' was computed by the equation

$$C' = \frac{A}{4\pi d}\left(1 + \frac{1}{\sqrt{\pi A}}\left(d + d\ln\frac{16\sqrt{\pi A}(d+d')}{d^2} + d'\ln\frac{d+d'}{d}\right)\right)$$

where A is the area, d the distance apart and d' the thickness of

[2] The disposition of condensers C', C'', cell, etc., earthed at e is suggested in Fig. 1.

the brass plates. Since A is equal 315 sq. cm., $d = .082$ cm., $d' = .67$ cm.,

$$C' = 305.6(1 + .0784) = 330 \text{ cm.}$$

This value will suffice for the present purposes, though it needs further correction by comparison with a standard condenser, not now at hand.

A special key was provided (Fig. 1) whereby C' could be switched into the electrometer system or out of it and put to earth. Hence in a series of successive discharges

$$(C'' + c)V = (C'' + C' + c)V',$$
$$(C'' + c)V' = (C'' + C' + c)V'',$$

etc., so that for n discharges, if the residual potential is V_n

$$V(C'' + c)^n = V_n(C'' + C' + c)^n,$$

from which the total capacity $C = C'' + C' + c$ is determinable in terms of C'. The results were:

Positive charge, $C'' + C' + c =$	1,445,	1,443,	1,422,
Negative charge, $C'' + C + c =$		1,482,	1,480,

Mean $C = 1,459$,

the experiments alternating from positive to negative charge, because of the marked drift by the electrometer system when isolated from the cell, as already specified. To measure the small capacities c, of the fog chamber, the same method with *ten* discharges suffices, if C'' is excluded and C' retained. Thus the data were successively found,

+ Charge, $c =$	11.8	12.4	12.2	12.9,
— Charge, $c =$	10.8	10.4	11.1	11.5,
Mean $c =$	11.3	11.4	11.6	11.2,

eliminating the drift in the final mean, $c = 11.4$.

Since the capacity c in terms of the effective internal radius R_2 and external radius R_1 the length l of the clindrical condenser may be written

$$\frac{1}{l} \log \frac{R_1}{R_2} = \frac{1}{2 \times 2.3 \times c},$$

the constant c furnishes a mean value for the factor on the left. The ratio of 4.6 c to the measured value of $(\log R_1/R_2)/l$ was .568, a reduction factor used throughout the tables below.

4. *Method Pursued.*—If C is equal to $C''+C'+c$ we may write the equation for the negative ionization N (positive charge)

$$N=\frac{C\ln R_1/R_2}{600\pi lve}\frac{d(\ln V)}{dt}=\kappa\frac{d(\ln V)}{dt},$$

where R_1, R_2 and l are the effective radii and length of the condenser, $10^{10}e=3.4$, $v=1.51$ cm./sec., and $u=1.37$ cm./sec., the velocity of the negative and positive ions in the unit field, volt/cm., in case of moist air. The factor $(\ln R_1/R_2)/l$ is replaced by $1/2C$, as specified in § 3, which must here be regarded as an adequate correction for the ends and the imperfect cylindricity of the condenser fog chamber.

Similarly the equation for the positive ionization is (negative charge),

$$N'=\frac{C\ln R_1/R_2}{600\pi lue}\frac{d(\ln V')}{dt}=\kappa'\frac{d(\ln V')}{dt}$$

and the total ionization is therefore $N+N'$.

The experiments below will show that even if the fog chamber is put to earth, there is a drift towards negative potential, sufficiently steady to be eliminated in the mean results. Hence if V_0 be the effective negative potential of the wet glass envelope we may write tentatively,

$$N=\kappa\frac{d\ln(V-V_0)}{dt}\quad\text{or}\quad N\left(1-\frac{V_0}{V}\right)=\kappa\frac{d(\ln V)}{dt}$$

where V_0 is intrinsically negative.

Similarly,

$$N'\left(1+\frac{V_0}{V}\right)=\kappa'\frac{d(\ln V')}{dt}.$$

Hence if $V=V'$, $N+N'$ the total ionization is again

$$\frac{d}{dt}(\kappa\ln V+\kappa'\ln V').$$

Direct experiments, however, show that the drift results from the influx of a high permanent positive voltage. Curiously enough even when the lighting circuit is cut out, the effect remained with undiminished intensity. It will appear elsewhere, that in the absence of radium and of initial charge in the condenser, the equation $I_0 = C\dot{V}_0$ where $\dot{V}_0$ for any given ionization is a constant negative quantity, applies very closely within the limits of measurable $\dot{V}_0$ values. Hence in the presence of radium in the core of the cylindrical fog chamber and a positive charge,

$$I_0 + 600\pi lVNev/(\ln R_1/R_2) = C\dot{V}.$$

Thus in this case

$$NV = \kappa d(V - V_0)/dt; \quad -N'V' = \kappa' d(-V' - V_0)/dt,$$

and for the same $V = V'$, to a first approximation

$$N + N' = d(\kappa \ln V + \kappa' \ln V')_{V=V'}/dt,$$

as before. If the equation for N is integrated and $N/\kappa = K$, since $I_0 = C\dot{V}_0$, $\dot{V}_0$ being intrinsically negative,

$$V = \epsilon^{-Kt}(V_c - \dot{V}_0/K) + \dot{V}_0/K; \quad V' = \epsilon^{-K't}(V_c' + \dot{V}_0/K') - \dot{V}_0/K',$$

where V_c and V_c' are the initial positive and negative potentials. The constant $\dot{V}_0$ increases with the strength of the ionization but has a fixed value for a given ionization.

5. *Data: High Ionization: Currents*—The tables[3] investigated contain the mean potentials $\bar{V}$, the positive and negative logarithmic currents $d(\log V)/dt$ (apart from the constant), the apparent nucleation N positive and N' negative, computed from these data and additional information as to conduction leakage and effect of γ rays. In most of the cases the corresponding logarithmic currents due to γ rays outside the fog chamber was carefully measured in the same units, by placing a short hard-rubber rod between the end t of the aluminum tube, Fig. 1, and the wire leading to the electrometer. This cuts out the fog chamber but leaves the whole remaining circuit undisturbed. Similarly the leak value of $d(\log V)/dt$ in the absence of radium and due to mere conduction of moist parts is always quite negligible. Thus in the data in

[3] The tables will be removed for brevity, as Figs. 2–4 sufficiently reproduce the data.

question for relative logarithmic currents of the order of .035, the γ ray effect is .0010, the conduction leakage smaller than .0001. The other extreme, *i. e.*, the value of $d(\log V)/dt$ for the freely falling needle is about .1 in the same units. Hence it follows that if the needle falls faster than would be quite trustworthy, the auxiliary capacity selected is too small. The time interval between observations for V was 4 sec., throughout.

6. *The Same: Coronas.*—These results (to be given in Figs. 2*a* and 2) contain the data for the maximum ionizations obtainable with the radium tubelets I., II., III., IV., V. at my disposal. The corresponding corona was a large orange-yellow type, representing (in my former reductions) 506,000 nuclei in the exhausted fog chamber. I have supposed this to be equivalent to 653,000 when the fog chamber is at atmospheric pressure, seeing that the coronas are actually displaced during exhaustion; *i. e.*, at the maximum ionization does not coincide in the position with the largest corona on exhaustion,[4] but is displaced in the direction of the exhaust currents. The observation would seem to mean that exhaustion is more rapid than the reproduction of ions to restock the region of dilatation. In general this inherent discrepancy of a marked distribution of ionization increasing from end to end of the fog chamber is still outstanding. It is partially allowed for since the observations are made near the middle of the chamber where the average conditions supervene.

7. *The Same: Summary.*—The data given in Fig. 2*a* merely show the fall of potential in scale readings, in the successive observations 4 seconds apart, for positive and negative charges. Fig. 2 gives the corresponding positive and negative *apparent ionizations*. If the two curves between .8 and 1.2 volts be considered, the mean ionization of each is

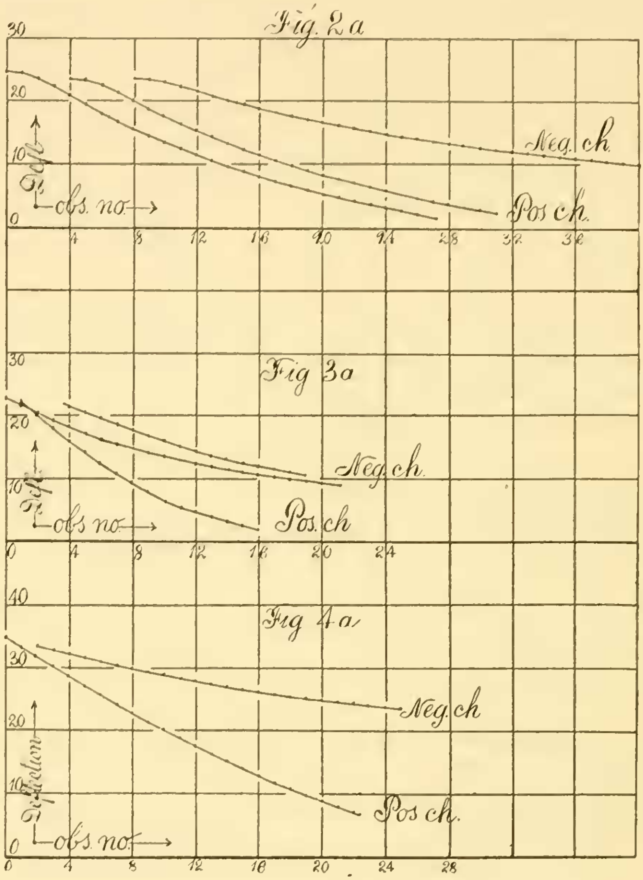
Apparent positive ions (negative charge), $N =$	540,000.
Apparent negative ions (positive charge), $N' =$	1,164,000.
Total true ionization, $N + N'$ $=$	1,704,000.
Total nuclei caught,	650,000.

It will be seen that $N + N'$ is the true total ionization, positive

[4] See papers cited; also *Science*, XXVIII., p. 26, 1908.

and negative, if $10^{10}e = 3.4$. Only 65/170, or about 38 per cent., of this is actually caught in the given fog chamber on exhaustion, provided the old coronal values are corect.

If, however, it is assumed that negative ions only are caught



during exhaustion in the fog chamber in question, then the value of the electron would be

$$10^{10}e = 3.4 \times 2.62 \times \tfrac{1}{2} = 4.4 \text{ electrostatic units.}$$

The irregularities of the curves, Fig. 2, are due in part to fluctuations of the drift and in part to errors inevitable in derivations so close together; but such errors necessarily compensated each other in the mean values.

10. *Data: Moderate Ionization: Electrical Currents.*—These results were obtained by placing but one radium tubelet, No. IV., in the aluminum tube tt' of the condenser-fog-chamber. The data were found in the same way as in the above. $N = \kappa d(\log V)/dt$, as usual.

Both positive and negative currents were observed in succession and the true total ionization is $N + N'$ as before. Moreover, the capacity of the condensers were widely varied, 410 to 1,459 cm., without showing serious divergences.

11. *The Same: Coronas.*—At a fall of pressure of 21 cm. (and somewhat below) or $\delta p/p = .27$, the nucleation was stationary and equal to $N = 113{,}000$ in the exhausted fog chamber. At atmospheric pressure therefore $113{,}000 \times 1.37 = 154{,}000$ nuclei should have been present. The effect of a charge on the core of the condenser did not appreciably diminish the nucleation.

12. *The Same: Summary.*—The successive observations in scale parts at intervals, 30 seconds apart, are shown in Fig. 3*a*, the slopes only being of interest. The apparent values of N are given in Fig. 3. All the four series show about the same drift, even though taken many days apart. The condenser effect (excessive rapidity of needle) may be considered eliminated for capacities greater than 500 cm.

By averaging the ionizations between $V = .6$ and $V = 1.24$ in both curves the data found are as follows:

Apparent negative ions, N	$= 278{,}000$.
Apparent positive ions, N'	$= 107{,}000$.
True total ions, $N + N'$	$= 385{,}000$.
Total nuclei,	180,000.

Hence about 47 per cent. of all the ions were caught on exhaustion, if the values of u, v, e, N, inserted, are correct. Supposing that negative ions only are caught in the above fog chamber, the value of the electron would be

$$10^{10}e = 3.4 \times 2.14 \times \tfrac{1}{2} = 3.6 \text{ electrostatic units.}$$

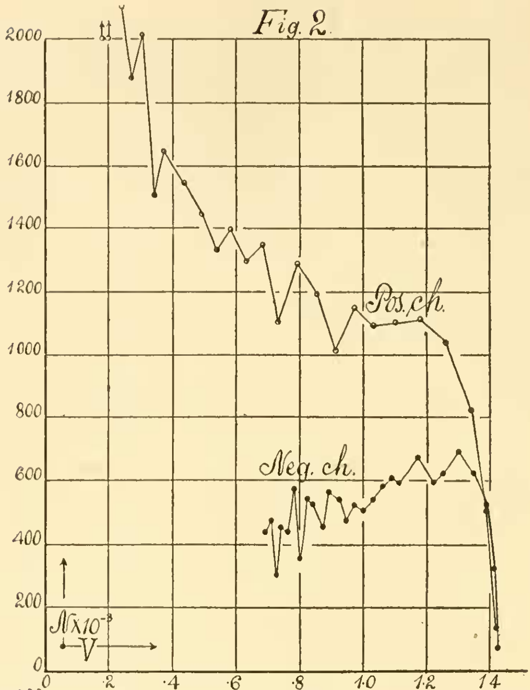


Fig. 2.

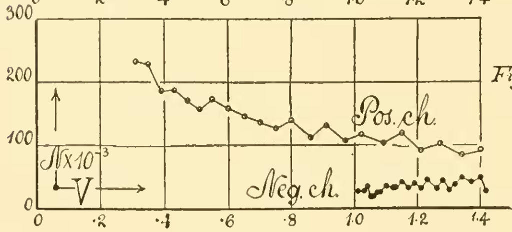
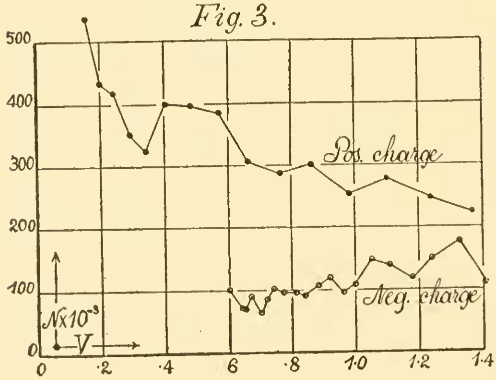


Fig 4.

Fig. 3.



13. *Data: Small Ionization: Electric Currents.*—In the next series of experiments the aluminum tube tt', Fig. 1, was surrounded by a lead tube with walls .117 cm. thick, leaving the γ rays only effective and these much reduced in intensity. The data are sufficiently given in the following charts.

14. *The Same: Coronas.*—The coronas found at a drop of pressure similar to the above $\delta p/p = .300$, corresponded in my tables to 46,200 nuclei in the exhausted fog chamber. Hence at atmospheric pressure there should have been 64,000. The effect of charging the core was not definite.

15. *The Same: Summary.*—The drop of potential in scale parts, in successive intervals 30 cm. apart, is given in Fig. 4*a*, showing how much slower the negative charges are lost than the positive charges. The apparent values of N are given in Fig. 4, to which remarks similar to those already made are applicable. There is the usual drift and the usual temporary fluctuation.

If the mean data be taken between $V = 1.1$ and 1.4 volts, the results are

Apparent positive ions,	N'	$=$ 37,000.
Apparent negative ions,	N	$=$ 98,000.
True total ionization,	$N + N'$	$=$ 135,000.
Total nuclei caught,		60,000.

It follows, then, that about 44 per cent. of the total ionization computed from $10^{10}e = 3.4$, u and v, is caught on condensation.

If we suppose the negative ions only are caught in the above fog chamber the electron value is

$$e \times 10^{10} = 3.4 \times 2.3 \times \tfrac{1}{2} = 3.9 \text{ electrostatic units.}$$

Conclusion.—Supposing the electron value to be $10^{10}e = 3.4$ electrostatic units as before, the normal velocities of the ions in wet air to be $u = 1.37$, $v = 1.51$ cm./sec., in the volt/cm. field, the coronal equivalent of the ions caught in the above fog chamber is in the several cases,

Total ions, 1,700,000,	Total nuclei, 38 per cent.
385,000,	47 per cent.
135,000,	44 per cent.

When N is 1,700,000 the coronas are too diffuse for sharp specification. If it is assumed that negative ions only are caught, and if the nucleations corresponding to the coronas seen in the given fog chamber be taken as developed in my earlier work, then for

$$N + N' = 1{,}700{,}000, \quad 385{,}000, \quad 135{,}000,$$

the electron values are

$$10^{10}e = 4.4, \quad 3.6, \quad 3.9,$$

electrostatic units.

With regard to the two parts of this paper that need revision the first, the comparison of the computed condenser capacity C' with a standard, is a minor matter; but the other, *i. e.*, the marked distribution of ionization along the axis of the fog chamber, will need further inquiry. In the direction of the exhaustion the amount of ionization may vary in the ratio of more than 1 to 2, in a fog chamber of about one half meter of length; and this under conditions where there should apparently be no variations and irrespective of the production of radiation from within or from outside of the fog chamber.

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